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DESCRIPTION OF AN ELECTROPALATOGRAPHIC SYSTEM

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After more than a hundred years of palatography, interest among linguists for techniques, the principles of which up until recent years had hardly evolved at all, might have been expected to be on the decline. In fact this is not the case. The readily interpretable nature of a palatogram is perhaps sufficient to explain the continuing interest for this type of document even among those linguists who are put off by the extreme sophistication of much physiological research. No doubt the ease with which palatographic documents can be interpreted, resulting in a certain superficiality, has been responsible, in some cases, for an excessive use of cues of place of articulation in phonetic descriptions, the foundations of which, today, seem somewhat doubtful when the linguist has not taken into account the general form of the tongue at the moment of articulation. Furthermore, it has become traditional to decompose the overall palatographic image in order to reconstruct the sequence of lingual contacts by comparing the palatograms of phonic sequences where for example the same consonant appears in a variable vocalic environment.

Despite the precision of these interpretations, the need was felt for a less static system which would enable the investigator to follow directly the temporal sequence of the regions of contact between the tongue and the palate, without limitations of any kind. This has been made

possible by the development of electropalatography which, after a slow start some fifteen years ago can now be considered one of the most advanced techniques of physiological phonetics. One can readily imagine the incredible wealth of data on the functioning of spoken language, particularly concerning the phenomena of lingual coarticulation which will become available in the years to come thanks to the simultaneous use of electropalatography and X-ray films. The recording of the sound source synchronised with each X-ray picture will make it possible to follow up with any desired acoustic or perceptual analysis.

This vast research programme which has been undertaken at the Institut de Phonetique d'Aix (laboratoire associé du C.N.R.S.) is now well under way, after the development of an electropalatographic system of which, in the rest of this paper, we shall outline the technical characteristics, the operating conditions and the various modes of treatment of the data thus obtained, particularly where these differ from other existing electropalatographic systems. We shall also point out, as we go along, various improvements which we intend to make to this material without changing its basic conception.

The electropalatograph consists of two main parts connected to each other: (a) a palatal plate equipped with electrodes connected to electric wires and (b) an electronic system comprising of a sine-wave generator and a palatal-electrode signal detection and processing unit.

The Palatal Plate

The electronic circuits used in various types of electropalatography are often described in abundant detail, information concerning the palatal plate however is generally given far more sparingly. And yet, as was shown by the discussion between proponents of direct palatography (by painting the tongue) and indirect palatography (using an "artificial palate"), the fact of placing a plate of a certain thickness against the hard palate is not without effect on the production of speech. While the majority of phoneticians today are convinced of the superiority of direct examinations, particularly considering the

considerable progress made in the field of intrabuccal photography, electropalatography brings up once more the delicate problems concerning the use of palatal plates. The conditions of construction of "artificial palates" have of course changed considerably in recent years, taking advantage of the progress made in dentistry in general. It is nonetheless a fact that one of the biggest obstacles for the development and diffusion of electropalatography comes from the difficulty of perfecting palatal plates. Before an intensive and reliable use can be made of these techniques, a number of questions need to be answered:

(a) Do the "artificial palates" fit the palatal (and if necessary dental) morphology of the subject perfectly, without compressing the palatal mucous?
(b) Does the thickness which is necessary for the plate, to prevent it from being deformed in use, give rise to compensatory positions and movements when the subject speaks (including any possible modifications of jaw-positions)? The fact that patients get used to artificial dentures, with variable modifications to their voice, seems to imply the existence of a process of adaptation.
(c) Does the technique used for fixing the plate (usually by means of metal hooks) hold the plate securely in position during the experimentation, even when the subject swallows?
(d) Do the plates need to be replaced frequently due the ageing of the material used and resulting deformations?
(e) Is the join between the electrodes and the plate sufficiently waterproof to prevent any eventual risk of infiltration of saliva by capillarity along the electric wires?
(f) Is it possible to achieve perfectly hygienic conditions of use without damaging the plate? If not, does the re-use of the plate in experiments at different times present a danger for the subject (risk of mouth infections)?

In order to answer these crucial questions unambiguously, we decided to undertake a first phase of

experimentation during which several prototypes manufactured in various different ways were submitted to a series of detailed examinations (Fig. 1).

Technique for the production of the palatal plates (Fig. 2). Based on the results obtained from the above-mentioned experiments, and following several tests the results of which were positive, we finally decided to adopt the BIOSTAR technique for the production of the "artificial palates." This process is the result of a collaboration between two West-German companies: BIOS GESELLSCHAFT OSNABRUCK and SCHEU DENTAL LETMATHE. It consists of thermoplastic modelling by compression of plates of sheets of variable thickness, dimensions and hardness. Our final choice was of extra-hard transparent plates of 0,5 mm thickness in prepolymerised acrylate, totally exempt from any monomeric residue, designated by the term IMPRELON. The model of the upper dental arch, obtained by extremely precise impression with OPTOSIL using the XANTOPREN method is placed on the work-plate of the BIOSTAR APPARATUS. The sheet of IMPRELON is blocked with a bayonet-joint against the compression chamber and heated by means of an infra-red diffuser on the side which is to be applied to the model thus making it possible to obtain extremely precise moulding. The frame holding the plastic sheet is swung over with its pressure-chamber onto the model which is already in place on the work-plate. Looking it into place lets compressed air into the tank automatically moulding the sheet of plastic against the model. The opening of an outlet-valve releases the pressure and allows cool air to circulate and cool down the plate.

At this point in the production of the plate, the shee of IMPRELON entirely covers the teeth of the model, both on their palatal and on their vestibular faces, as well as the complete vestibular zone. There is no good reason not to make use of this fact since the under-cut of the neck of the teeth and the vestibule constitute the best possible means of holding the plate in place and make the use of metal hooks unnecessary. It seemed, however, important not to cover the vestibular face of the incisors in order to reduce any possible interference with the closing of the

mouth. The cutting-line for the plate was consequently as follows: it stops, at the front of the plate, at the level of the middle third of the palatal face of the incisors (this can be extended to the free edge of the incisors). The line then runs, at the level of the canines fairly high up into the vestibule, up to approximately 10 mm above the neck of the premolars and molars, covering the tuberosities at the back, and on the palate itself follows the line of the postdam (Fig. 2A). The advantages of these sheets of Imprelon moulded according to the Biostar technique and cut as described above are numerous. First of all the artificial palates which are produced in this way reproduce the palatal morphology extremely faithfully, particularly in the front alveolar region where the palatal palpillas are reproduced with great precision, which is a considerable progress compared to artificial palates in acrylic resin. The fact that the teeth are covered provides a satisfactory solution to the otherwise delicate problem of the passage from the neck to the palatal face of the teeth, where it is difficult to avoid both excessive thickness of the material used (particularly in the case of acrylic resin) a detachment of the plate near the teeth. This explains why the cut which is generally adopted stops at the level of the necks. This lack of covering for the teeth deprives certain users of electropalatography of information which could otherwise be of interest to them. This is particularly the case for orthodontic specialists who are concerned with the relationship of tongue to teeth during speech and during swallowing: the use of palatal plates covering the teeth could give them the means of following minor interpositions and protusions of the tongue during speech which are not always easy to detect. While this single palatal plate gave us entire satisfaction so that we were led to adopt it as "artificial palate" for indirect palatography, with excellent results, the development of the electrodes presented us with a number of difficulties.

Construction and positioning of the electrodes (Fig. 2). Within the framework of the research-programme E.L.P.A.I., three palatal plates were developed: the construction of the plates followed the same principle in each case, the only difference being in the positioning of the electrodes

which varied from one prototype to another. The first prototype ELPAI I. 1., Fig. 2D., had only twelve electrodes which were positioned to record the maximum number of tongue-contacts for the articulation of French consonants (based on the results of the preliminary experimentation). The second plate, ELPAI I. 2. Fig. 2E., was fitted with thirty-eight electrodes in order to allow a more detailed exploration. The purpose of this second plate was above all to check whether it was possible to increase the number of electrodes without abandoning the Biostar technique: the results were positive in all respects. The third prototype, ELPA I. 3. Fig. 2B, C., was designed with a view to carrying out a series of studies on the regions of articulation of anterior consonants in French: 12 electrodes were placed in the retro-incisive region, from the neck of the central incisors to the far limit of the first pre-molars, with the remaining four electrodes placed on the lateral edges of the palate.

In all three cases, the techniques used for placing the electrodes were the same. The desired positions of the electrodes were first marked with small circles on the mould of the dental arch. When the plate is subsequently placed on the model the positions can be marked on the transparent plate. The electrodes were manufactured by removing the protective enamel by flame from one end of each of the 16 copper wires used (the diameter of the bare wire is then increased until a copper ball of approximately 0,6 mm is obtained which is fixed in place, with its linking wires by means of a special adhesive (methylic butyl acetate). The wires are then gathered into two bundles one each side of the dental arch, at the level of each tuberosity and are placed under a thermo-shrinking sheath. This sheath, itself held in place by the same adhesive, takes the bundle of wires from the level of the neck of the third molar up to the canines. When the plate is placed in the subject's mouth, the sheaths leave the mouth from the corners of the lips.

The present state of the palatographic plate. At this stage of development (Fig. 2B), satisfactory solutions have been found to most of the problems outlined above: both in

as far as respecting the palatal morphology is concerned and for the thickness and stability of the plate. There are, however, a number of possible difficulties during usage caused by the copper balls or the wires breaking. Furthermore it proved impossible to assure perfectly hygienic conditions of use for such an apparatus. In order to increase the strength of the plate and to protect the electrodes and the wires we decided to make use of a second plate, also made with the Biostar technique and stuck to the first using ACRYSIVE (Fig. 2C.). It is possible to make use of the stretching of the material which occurs when it is heated but nonetheless the final thickness of the new plate was close to 1 mm in several places. As the electrodes were now sandwiched between two sheets of Imprelon the plastic covering then was removed by means of a needlepoint. Once the conductivity of each of the connecting wires had been tested, the apparatus was ready for use.

Possibilities of improvement. Without abandoning the Biostar technique which has given entire satisfaction, several possible improvements have been envisaged. It should be possible in the very near future to return to a plate of less thickness (0,5 mm) covered on the inner surface with a varnish or a resin protecting the wires and the electrodes. Furthermore, the use of silver wires and electrodes should ensure a better conductivity of the current. Our present researches, however, are aimed at developing the use of electropalatography (for therapeutic and pedagogical purposes). To do this it will be necessary to reduce the cost of each plate. One solution would be to construct a single "artificial palate" per subject and to interchange the wires and electrodes from one plate to another. Another possibility which we had already envisaged in 1975 would be to use sheets of Imprelon with wires and electrodes incorporated which could then simply be moulded to the shape of each subject's palate.

The Linguo-palatal Contact Processing Unit

The sine-wave generator. The electropalatographic system we use was originally outlined by Kydd and Belt (1964) and needs only a single source for the excitation signal. This signal is an alternating current of 20 kH which is

passed through the subject's body by means of an electrode which we place on his forehead by means of a suction contact as used for electrocardiography. The current is supplied to the electrode by means of a sine-wave generator which consists of an oscillator with a very stable frequency and an automatic gain-control amplifier. The output current is limited to 100 microamps by means of a special circuit. The output voltage of the generator varies with an infinite resolution of 0 to 10 volts peak to peak.

The palatal electrode signal processing unit. One of the numerous advantages of the KYDD and BELT system is to allow the processing of signals from the palatal electrodes (or palatal contacts) by means of a number of identical relatively simple circuits. They consist of a voltage amplifier of high input impedance (10 M ohm) followed by a band-pass filter with a high Q factor adjusted exactly to the frequency of oscillation of the generator. A threshold detector, consisting of a hysteresis comparator produces a pulse when the input signal is above a certain threshold which is fixed at the same level for all the electrodes. These pulses are then sorted by means of a temporal filter and then, by way of opto-electric isolating circuits, fed to a sampling and memorising system. The sampling frequency is 100 Hz (thus giving a representation of linguo-palatal contacts every 10 ms). The operator can store in the memory the representation of the contacts at any moment he chooses. Finally, various interfaces make it possible to send the signals, in parallel, in three directions; (a) to a display panel, (b) to a galvanometric recorded and (c) to a computer, after multiplexing the various contacts.

The Operation of the Electropalatograph

The reliability of the detection of contacts. During the first tests, which we began running, at the beginning of our experiments on the tongue-electrode contacts, we noticed that certain signals were obviously not caused by contact between the tongue and the electrodes. In the case of some subjects the operation of the system showed a great deal of disturbance. To investigate this further we undertook a series of measurements of the conductivity of the saliva of

various subjects. A few drops of saliva taken from ten subjects were placed on two electrodes with a diameter of 1 mm and separated by 2,5 mm. The resistance between the two electrodes was measured by an Impedance bridge (General Radio Type) with an alternating excitation signal of 20 kH. Our results brought to light considerable differences between the conductivity of the saliva of various subjects. A second experiment using the same material made it possible to measure the resistance between the emitting electrode and the palatal electrode in actual contact with the tongue. The results of these two measurements presented in the table of Figure 3 show that in all but one case the total resistance of the circuit: emitting electrode - tongue - palatal electrode is lower than the resistance between two adjacent electrodes caused by the conductivity of the saliva. This means that it is necessary to make a very precise adjustment of the signal level and for the amplitude to be particularly stable. For this reason, we equipped the generator with an automatic gain control which allows a stability of 0,1% for the amplitude. The cut-off frequencies of the filters are adjusted exactly to the frequency of the oscillator. In order to avoid loss of gain of the filters caused by ageing of the components, we used a circuit known for the stability of his components. The threshold detector is a comparator to which we added a hysteresis in order to prevent it from being set off erratically at levels which are badly defined in relation to the threshold. Finally, to prevent it being set off accidentally, which despite all precautions is always possible, the comparator is followed by a circuit which is a temporal filter, and which eliminates any pulse which is below the period of the oscillator, i.e. 25 micro secs.

Visualisation of the contacts. The visualisation of the tongue-palate contacts is obtained by means of a panel representing a photograph of the palate in the mouth at a scale 4 x 1 (Fig. 4). In place of the electrodes, we fixed light-emitting diodes. Such a panel, despite its spectacular nature, is in practice not very efficient. It is in fact only used for pedagogical demonstrations where the subject produces isolated articulations and makes use of the possibility of storing the signals in the memory. In this case,

electropalatography can be favorably compared to classic indirect palatography. In order to achieve a long-term memorisation of articulatory movements, we made use of a video-recorder with a satisfactory pause. This method was however lacking in precision since the pause on a video-recorder is particularly difficult to position. This type of recording was consequently rapidly abandoned. A more efficient type of recording was made by the use of galvanometric recorders for the visualisation of the contacts as a function of time. We consequently made use of two Siemens L Oscillomink recorders with the same speed (Fig. 5). This method is very efficient since it allows for a high degree of precision but does not give a palatal representation. We are, however, using this method for the moment while waiting for the connection of the electropalatograph to our computer to be completed. The computer we use is a S.E.M.S. T 1600. The information from the contacts is sent via a 16 bit word after multiplexing. After processing, the results can be visualised on a TEKTRONIX 4012 screen and printed on a HOUSTON 8230 high-speed line printer. The sampling frequency of the palatal representation is fixed at 100 Hz, i.e., every 10 ms.

Intended Developments

Since we consider that the full use of the electropalatograph implies that other measurements be made simultaneously, we have envisaged a number of developments of the basic system. The first consists of the synchronic recording of the palatal representation and the acoustic spectrum, in order to establish correlations between articulatory realisations and the acoustic results. In order to do this, we are at present connecting our computer to a P.A.R. 4512 real-time analyser. This apparatus will make it possible to obtain spectra of 128 resolution-points in 10 ms, timed by the sampling clock of the electropalatograph. The second development will consist of the synchronisation of X-ray films of the vocal tract at 100 frames per second with the electropalatograph and the real-time analyser. We will thus dispose of three simultaneous analyses. The biggest obstacle at the moment is the distance separating the hospital where our X-ray equipment is installed and our

computer. The solution we are examining at the moment would be to make use of three track instrumental recording with one track for the vocal signal, one for the synchronisation taken from the supply of the X-ray tube, and the third for the palatal contact information.

After a first phase of trial and error, understandable in such a complex field as the analysis of speech production, we managed to find a certain number of solutions to the problems we came across which will, we hope, make it possible to increase the number of applications of electropalatography. While a certain number of improvements are still necessary for the material to function satisfactorily, we feel that we have now reached a point where the decisive factor will be the method of interpretation of a vast amount of new data, and it is here that the phonetician-physiologist comes into his own.

REFERENCES

Fujii, I. (1970). Ann. Bull. Res. Inst. Log. Phon. U. Tokyo, 4:67-75.

Fukimura, O., Tatsumi, F., Kagaya, R. (1973). J. Phon., 1:47-54.

Hardcastle, W. J. (1972). Phonet., 25:197-215.

Hardcastle, W. J. and Roach, P. J. (1977). Phon. Lab. Univ. Reading, 1:27-44.

Kydd, W. L. and Belt, D. A. (1964). J. Speech Hear. Dis., 29:489-494.

Ladefoged, P. (1957). J. Speech Hear. Dis., 39:764-774.

Mollard, R. J. (1975). Thèse, Université d'Aix-Marseille II.

Palmer, J. M. (1973). Phonet., 28:76-85.

Rome, J. A. (1964). QPR, RLE, MIT, 94:190-191.

Scheu, R. (1968). L'inf. Dent., 48:3-7.

Shibata, S. A. (1968). Ann. Bull. Res. Inst. Log. Phon. U. Tokyo, 2:28-35.

Witting, C. (1953). Stud. Ling., 7:54-68.

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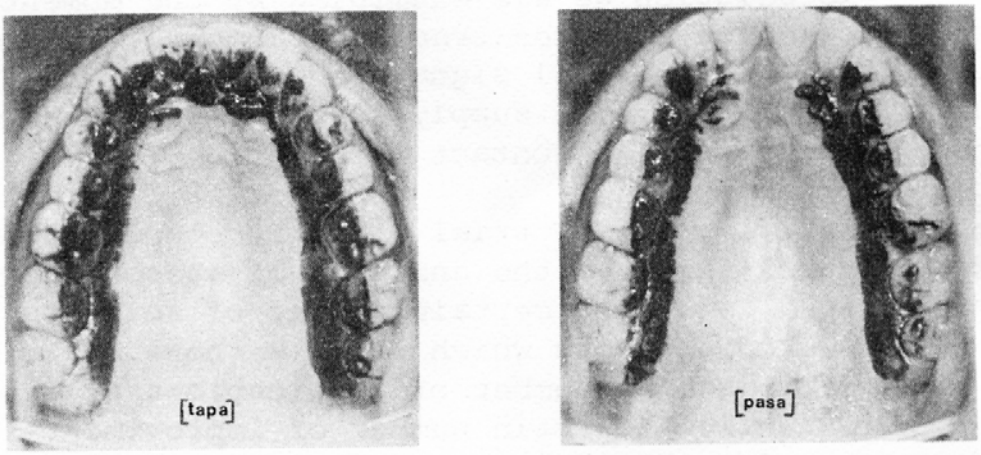
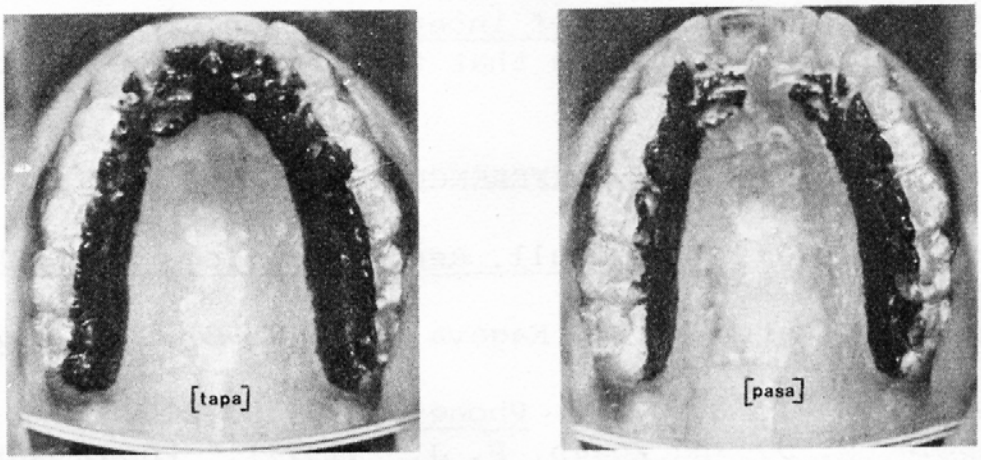
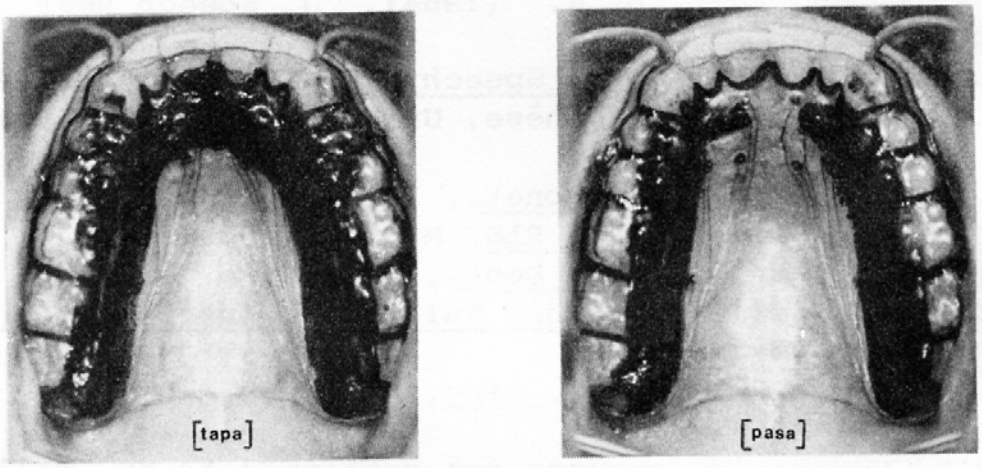


A. Direct palatography



B. Indirect palatography (artificial palate made with a sheet of IMPRELON of 0,5 mm thickness).



C. Electropalatographic plate (2 sheets of IMPRELON: 1 mm thickness).

Fig. 1: Effects of the thickness of the palatographic plate in phonetic realisations (/t/ and /s/ in French).

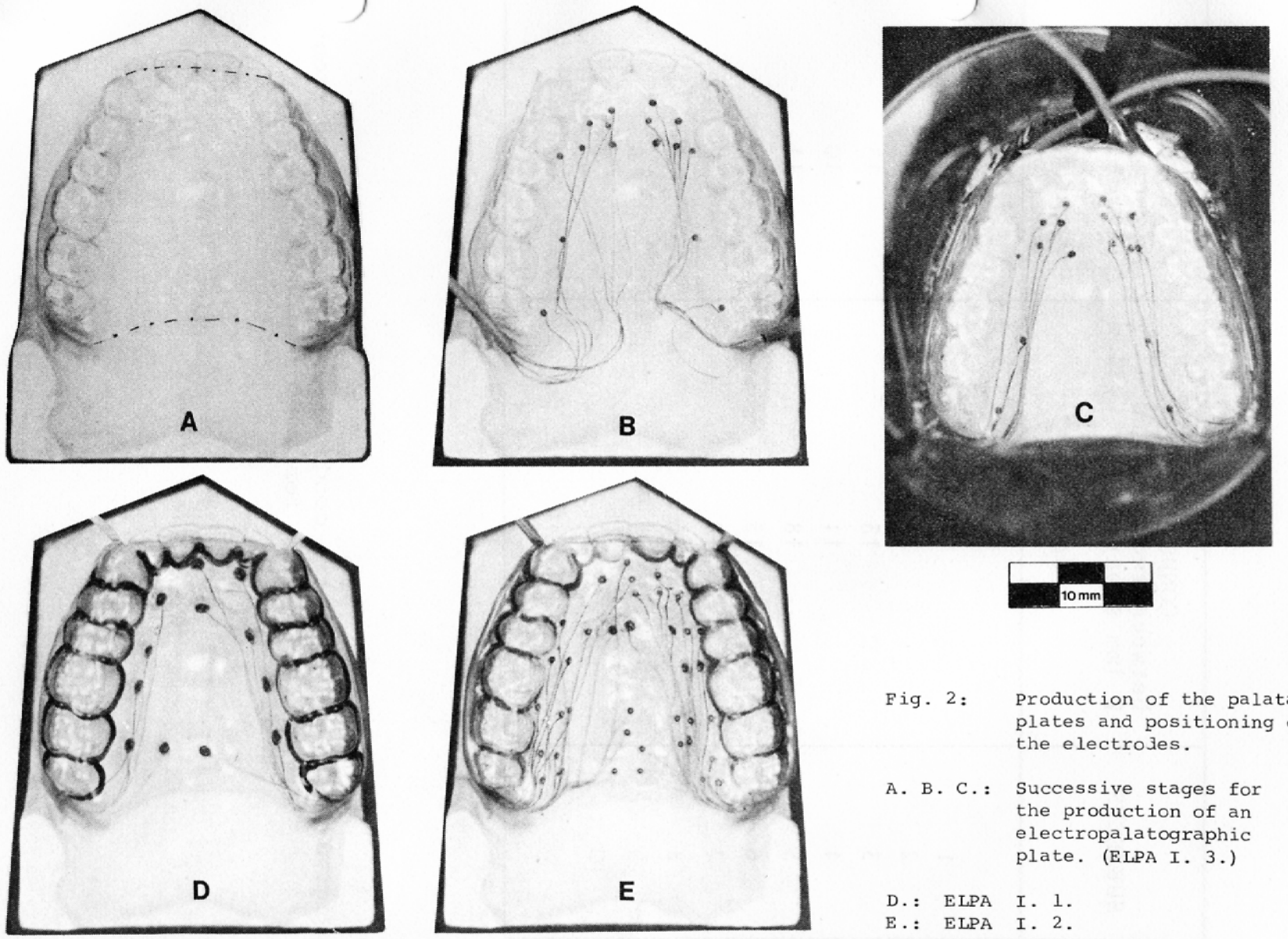


Fig. 2: Production of the palatal plates and positioning of the electrodes.

A. B. C.: Successive stages for the production of an electropalatographic plate. (ELPA I. 3.)

D.: ELPA I. 1.
E.: ELPA I. 2.

SUBJECTS	CONDUCTIVITY between two electrodes Ø 1mm separated by 2.54mm Kohm	RESISTANCE between frontal electrode and palatal contact Kohm
1	17	7
2	26	13
3	13	13
4	11	10
5	18	11
6	15	8
7	18	7
8	16	6
9	25	8
10	11	6

Fig. 3: Comparison of the conductivity of saliva and frontal-palatal resistance for different subjects.

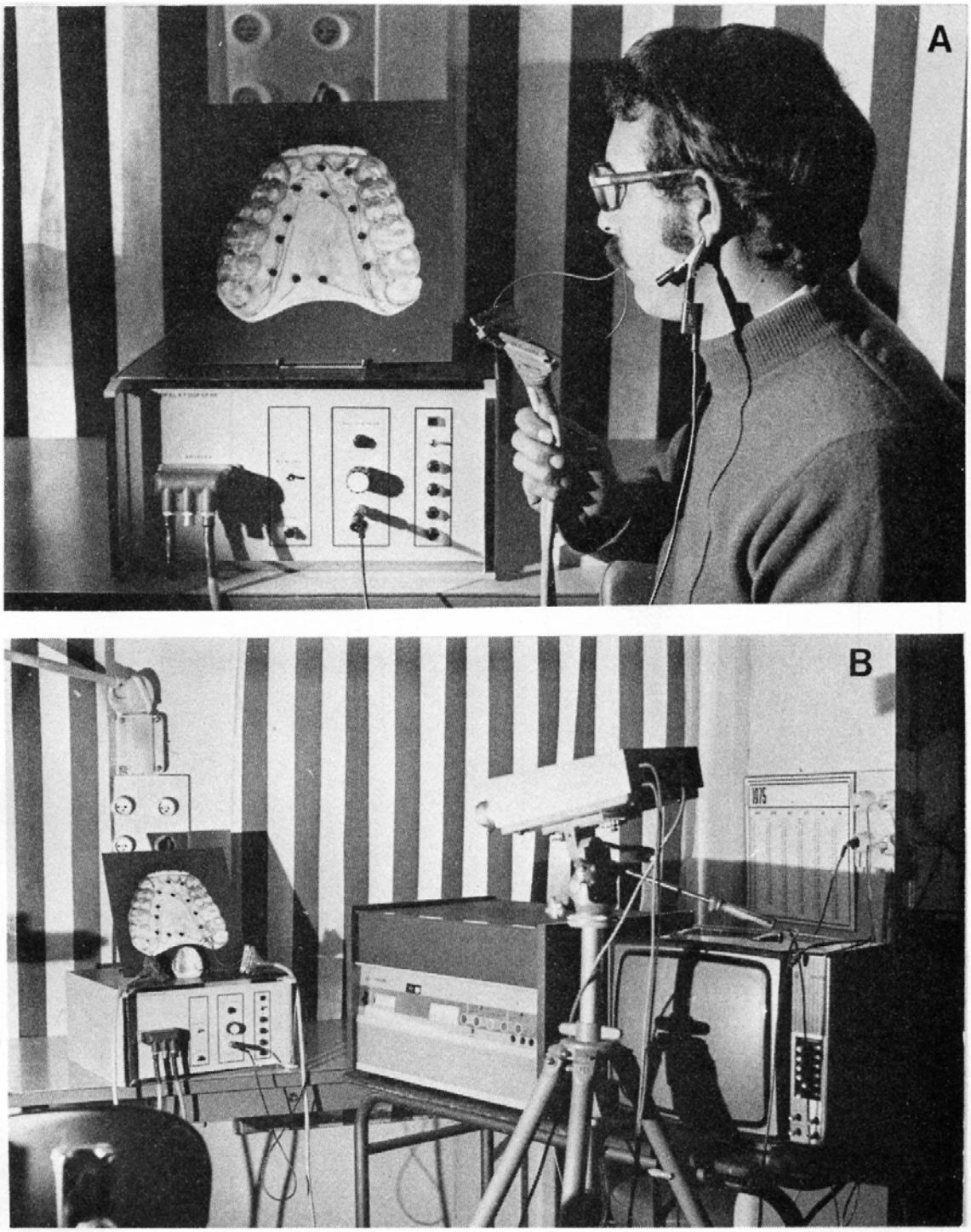


Fig. 4: Visualisation of the tongue-palate contacts by means of a panel (photography of the palate with light-emitting diodes):

A. Pedagogical direct demonstration.
B. Video-recording.

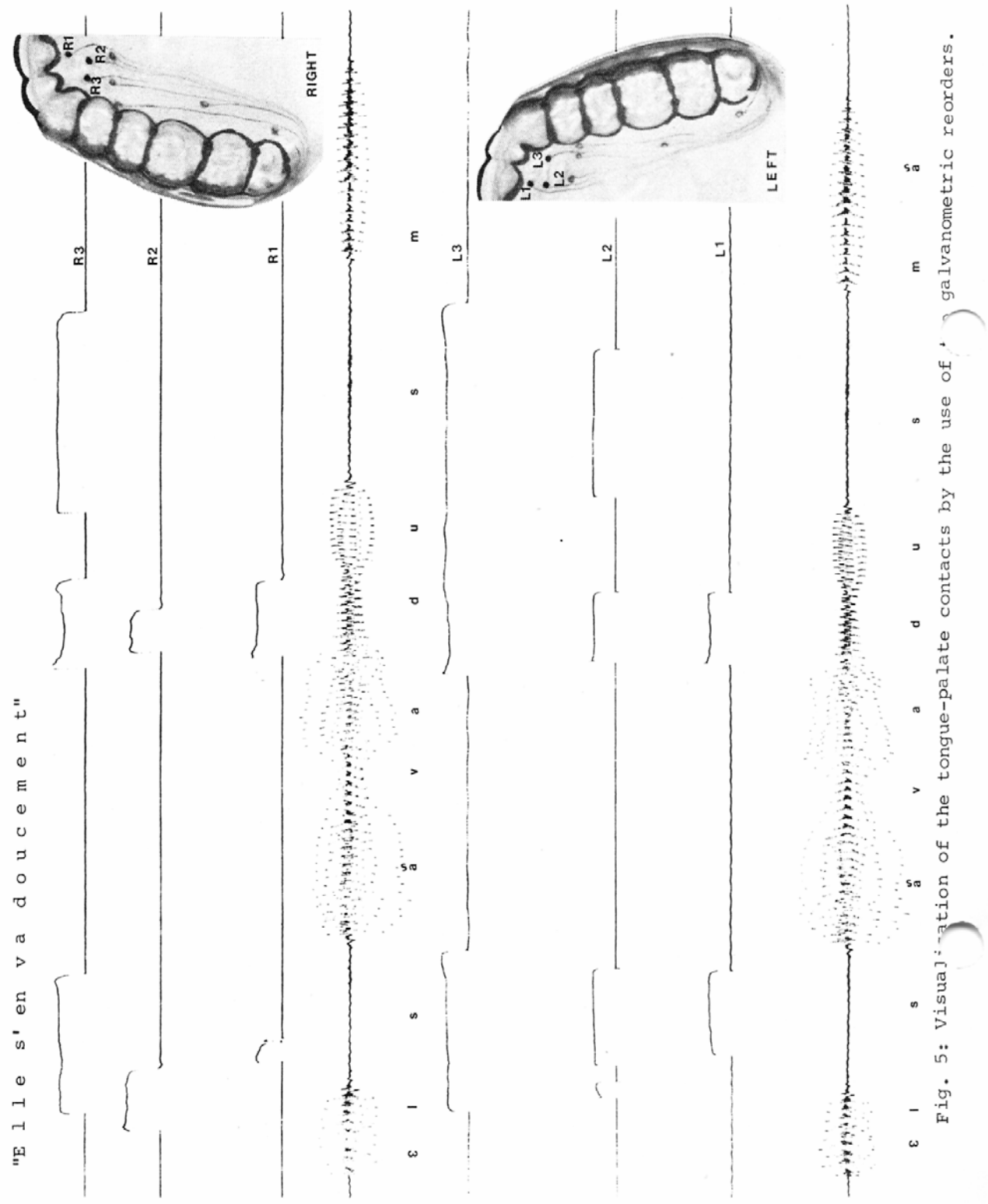


Fig. 5: Visualization of the tongue-palate contacts by the use of galvanometric reorders.